U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

2016 Annual Report Geothermal Technologies Office

March 2017

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The 2016 Annual Report of the Geothermal Technologies Office is a product of the United States Department of Energy, Office of Energy Efficiency and Renewable Energy.

GTO 2016 Annual Report Content

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This report spans calendar year 2016. Photographs have been accredited herein.

A Letter from the Director

Dr. Susan Hamm, Office Director

Reducing costs. Reducing risks. Creating an "everywhere solution."

Looking back on 2016, I'm reminded foremost of these overarching goals. Geothermal technology has never shown greater promise than it does right now, and the Department of Energy's (DOE) Geothermal Technologies Office's (GTO) commitment to enhancing America's energy security and diversity has never been stronger. Our ability to continue reducing the costs and risks associated with geothermal power will define our success in 2017 and beyond.

As indicated by an uptick in investments internationally, geothermal energy remains an essential piece of the renewable energy spectrum moving forward. Just below our feet lies a vast, stable, "always on" resource with the potential to power tens of millions of homes and businesses. Our nation's geothermal base currently provides 3.7 gigawatts of power, enough to fuel about 3.7 million homes. We expect these numbers to increase dramatically over the next decade.

Geothermal exploration and development historically have been limited to easily accessible regions. In the U.S., these areas are located in the western states, with California serving as a nexus of geothermal operations over the years. However, in part through GTO's research, it's clear that times are changing. Through GTO's Frontier Observatory for Research in Geothermal Energy (FORGE) initiative, geothermal exploration is expanding further within the subsurface, where vast, high temperature reservoirs yield the promise of significant gains in geothermal power. In a related effort, GTO's Play Fairway Analysis initiative uses advanced data analytics and geophysical interpretation outputs to identify new areas of exploration that offer a high probability of targeted drilling success, thus helping to dramatically reduce risk. And in a particularly innovative push, our Deep Direct Use initiative seeks to determine the feasibility of large-scale, low temperature, deep-well systems that could further extend geothermal's reach into new parts of the United States.

Establishing a new exploration threshold is always expensive in the earlier stages, but in the case of geothermal power, the investment is warranted. As we harness new resources and progress toward an "everywhere solution" that enables greater reach and impact, we're positioning geothermal to deliver an ever-increasing portion of our nation's electricity grid. This ultimately provides the American people with greater energy diversity, stability, and security.

As GTO works to reduce geothermal costs and risks, we're building solutions that provide mutual benefit across multiple areas of energy delivery. Our lead role in supporting geothermal-related subsurface innovation directly benefits other energy silos, including nuclear storage and oil and gas stimulation. In fact, the prevalence of these and other shared benefits related to subsurface control formed the genesis of the Energy Department's Subsurface Technology and Engineering Research, Development, and Demonstration (SubTER) initiative, allowing us to partner with various DOE offices including Fossil Energy, Nuclear Energy, Environmental Management, and the Office of Science to address subsurface research and development (R&D) challenges. This is one of our priority points of engagement, as more than 80% of the U.S. energy supply comes from resources below the ground. Like many of you, I'm eager to see what new efficiencies and solutions the SubTER team develops in the coming year.

We have ambitious goals at GTO, and these goals require the efforts of many bright and talented people. I want to thank everyone that has worked so hard to push geothermal innovation to new heights over the past year – our program and technology managers, support staff, consultants, Office of Energy Efficiency and Renewable Energy (EERE) colleagues, industry allies, and partners at numerous national laboratories and universities. I'm excited to see what's in store for 2017.

GTO always welcomes your questions and feedback. I encourage you to visit us at www.energy.gov/eere/geothermal, or submit your comments to geothermal@ee.doe.gov.

Dr. Susan Hamm
Director, Geothermal Technologies Office

The GTO Team.

Geothermal Technologies Office: An Overview

GTO staff attended the GRC Annual Meeting in Sacramento, CA

Geothermal energy, a virtually untapped energy resource derived from the earth's heat, is more vital today than ever—it supplies clean, renewable power around the clock, emits little or no greenhouse gases, and takes a very small environmental footprint to develop. By developing, demonstrating, and deploying innovative technologies, GTO's efforts help stimulate the growth of the geothermal industry within the renewable energy sector and encourage quick adoption of technologies by the public and private sectors.

GTO works in partnership with industry, academia, and DOE's national laboratories on research, development, and demonstration activities focused on:

Hydrothermal

Geothermal resources require fluid, heat, and permeability to generate electricity; conventional hydrothermal resources contain all three components naturally. These hydrothermal systems occur in widely diverse geologic settings, sometimes without clear surface evidence of the underlying resource.

Enhanced Geothermal Systems (EGS)

EGS are engineered reservoirs created to produce energy from geothermal resources that are otherwise not economical due to lack of water and/or permeability. EGS technology has the potential for accessing the earth's vast resources of heat located at depth to help meet the energy needs of the United States.

Low-Temperature and Coproduced Resources

Low Temperature and Coproduction is a GTO subprogram that supports hydrothermal development in geothermal resources below 572°F.

Systems Analysis

Systems Analysis is a GTO subprogram that identifies and addresses barriers to geothermal adoption in the U.S. and validates technical progress across the geothermal sector.

GTO is committed to developing and deploying a portfolio of innovative technologies for clean, domestic power generation. GTO funds activities across a full scale of technology readiness to drive the growth of cost-competitive energy applications.

GTO Invests in...

Research and Development for innovative technologies and methods that improve the process of identifying, accessing, and developing geothermal resources.

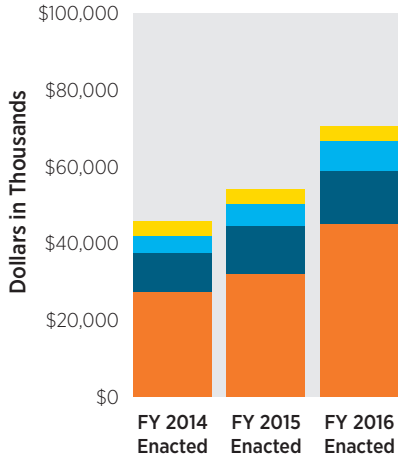
Facilitating Demonstrations that support field site validation to overcome technical obstacles and mitigate risk.

Addressing Market Barriers by solving non-technical challenges, including environmental permitting, demand for subsurface data, and analysis of our investments.

GTO SUBPROGRAMS

- Systems Analysis
- Low Temperature and Coproduced
- Hydrothermal
- Enhanced Geothermal Systems

GTO BUDGET



GTO continues to experience budget growth in support of innovative technologies that reduce the cost and risks of geothermal development. A budget increase of 29% was received from FY 2015 to FY 2016.

GTO's vision is to provide the nation with an abundant and renewable baseload energy source. Our goals and objectives include:

- Identifying and Accelerating Near Term Conventional Hydrothermal Growth
- Accelerating a Commercial Pathway to and Secure the Future with EGS
- Overcoming Deployment Barriers
- Accessing Additive Values
- Collaborating on Solutions to Subsurface Energy Challenges

Identifying and Accelerating Conventional Hydrothermal Growth and Geothermal Opportunities

Play Fairway Analysis – Continued Efforts to Map Geothermal

GTO announced the selection of six projects to continue with Phase 2 Play Fairway Analysis (PFA) activities. GTO awarded $4.1 million to six of the eleven Phase 1 projects from the 2014 PFA Funding Opportunity. The concept of PFA is being used to identify prospective geothermal resources in areas with no obvious surface expression by mapping the most favorable intersections of heat, permeability, and fluid. PFA Phase 2 moves the projects from desktop analysis to collecting new geochemical, geophysical, and geological data in the field, with the ultimate goal of identifying drilling targets for Phase 3.

The projects selected for Phase 2 funding continue to address the overarching theme of uncertainty quantification and reduction. All of the teams have had extensive field campaigns in Phase 2, collecting new data. The teams deployed a wide variety of geothermal exploration tools in 2016 including magnetotelluric, seismic, shallow temp probes, Light Detection and Ranging, chemical sampling, and field mapping.

Finding more effective exploration methods will address a major barrier to increased geothermal energy production by lowering the high upfront risk and cost of project development. By improving success rates for exploration drilling, this data-mapping tool will help attract investment in geothermal energy projects and significantly lower the costs of developing geothermal energy.

Exploring Geothermal Across the Nation: Deep Direct Use

GTO released a Deep Direct-Use (DDU) funding opportunity with up to $4 million for research and development projects led by the private sector, universities and national labs to pursue feasibility studies of large-scale DDU systems. DDU systems are an emerging technology area in the geothermal sector that draw on lower temperature geothermal resources. Deeper than geothermal heat pumps and other conventional direct-use systems, DDU is deployable at a similar temperature range—between 100°F and 300°F—but at a much larger scale. DDU maximizes system efficiencies and return on investment. This new technology could result in large-scale, low-temperature geothermal applications that create greater opportunities for geothermal resource development throughout the United States, an "everywhere solution."

As highly efficient systems, geothermal DDU operations extract the most energy possible from the local geothermal resource. Rather than using geothermal heat to produce electricity, DDU uses hot fluids from underground to directly heat and cool facilities. Directly using geothermal energy in homes and commercial operations can be much less expensive over the long run than traditional energy sources because it reduces electricity demand and replaces the need for electric-driven heating and cooling appliances.

Although direct-use is the oldest, most versatile and most prevalent form of geothermal energy, deep direct-use systems have not been developed in the U.S. largely due to technical, cost, and institutional barriers. The DOE's funding opportunity aims to help unlock these lower temperature geothermal applications for near-term deployment and support the goals of improving energy efficiency in manufacturing while reducing the energy bills of businesses and institutions nationwide.

Akutan – Geothermal Drilling in Action

Geothermal drilling along Alaska's remote island of Akutan may deliver enough power for nearby a town and harbor. Neighboring a volcano in a remote part of the Aleutian Island Chain, the island hosts the largest seafood producer in North America, which could be completely powered by geothermal energy.

Funded by GTO and the State of Alaska, the city of Akutan continued development efforts towards a geothermal power system in 2016. This year marked drilling operations with the planning and completion of a 1,955 ft. confirmation well during August-September. The area is one of the most prospective sites for geothermal power production in Alaska.

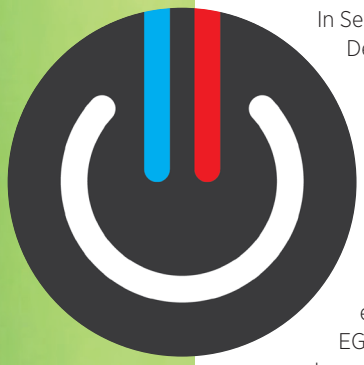
Three pressure and temperature surveys have been conducted since the drilling completion. A maximum temperature of more than 325°F was detected at about 500 ft. Once the well has had time to reach thermal equilibrium, another temperature survey will be completed that is expected to show even higher temperatures. Continued observation, including a flow test, is planned for the summer of 2017.

GTO Hydrothermal Goals:

- Lower risks and costs of development and exploration
- Lower levelized cost of electricity (LCOE) to 6 cents/kWh by 2020
- Accelerate development of 30 GWe of undiscovered hydrothermal resource

Accelerating a Commercial Pathway to EGS

Investing in the Future of EGS: FORGE



In September 2016, the Energy Department announced $29 million in funding for the University of Utah and Sandia National Laboratories (SNL) for FORGE Phase 2 activities. The ultimate FORGE field laboratory, dedicated to cutting-edge research on enhanced EGS, could unlock access to a domestic, geographically diverse source of clean energy with the potential to supply power to up to 100 million homes in the United States.

The FORGE initiative consists of three phases. The first phase, kicked off in 2015, consisted of five teams and their proposed FORGE sites in California, Idaho, Nevada, Oregon, and Utah. These five teams spent a year completing mission-critical technical and logistical tasks to demonstrate their candidate site's viability and show the team's capability of meeting FORGE objectives and developing plans for Phase 2. Phase 1 tasks included conceptual geologic modeling and the creation of comprehensive plans for data dissemination, intellectual property, environmental, health and safety information, communications and outreach, stakeholder engagement, R&D implementation, and environmental management. In the summer of 2016, these materials were reviewed by U.S. Department of Energy staff and a team of subject matter experts. Based on the review, two teams, SNL and University of Utah, were selected for Phase 2A.

The SNL's team and the University of Utah's team will focus their Phase 2 efforts on fully instrumenting, characterizing, and permitting their candidate sites for a single, full-scale operations at FORGE in the third and final phase. These Phase 2 teams are currently in Phase 2B, concentrating on NEPA and other environmental permitting, along with initial site characterization.

Subject to the availability of appropriations, Phase 3 is dedicated to the full implementation of FORGE at a single site. This phase will be managed by an innovative collaborative research team and strategy, and executed via annual R&D solicitations designed to improve, optimize, and drive down the costs of deploying EGS. In this phase, partners from industry, academia, and the national laboratories will have ongoing opportunities to conduct new and innovative R&D at the site in critical research areas such as reservoir characterization, reservoir creation, and reservoir sustainability.

GTO EGS Goals:

- Demonstrate 5 MW reservoir creation by 2020
- Lower LCOE to 6 cents/kWh by 2030

Advancing Enhanced Geothermal Systems: EGS Lab Call

In October 2016, GTO announced up to $9 million in funding for the multi-lab, multi-year EGS Collab effort.

This FY 2017 EGS Lab Call is focused on the EGS Collab, which will, over the next three years, act as the bridge between laboratory scale stimulation/rock mechanics studies and the large field scale of the future FORGE site.

The EGS Collab is envisioned as a small-scale field site where the geothermal reservoir modeling and research community will establish validations against controlled, small-scale, in-situ experiments focused on rock fracture behavior and permeability enhancement. The EGS Collab will provide the opportunity for reservoir model prediction and validation, in coordination with in depth analysis of geophysical and other fracture characterization data with an ultimate goal of understanding the basic relationship between stress, seismicity, and permeability enhancement. Identification of these parameters, as well as understanding how they change throughout the EGS development phases, are critical to achieving commercial viability of EGS.

This effort will address critical and fundamental barriers to EGS advancement by facilitating direct collaboration between the geothermal reservoir modeling community, experimentalists, and geophysicists in developing and implementing well-field characterization and development, monitoring, and stimulation methods.

In early 2017, GTO announced the selection of Lawrence Berkeley National Laboratory as the lead of the Collab effort with their SIGMA-V project. The EGS Collab SIGMA-V project is a multi-lab, private industry, and academic collaborative research project that brings together some of the world's most skilled and experienced scientists and engineers in the areas of subsurface process modeling, monitoring, and experimentation to focus on intermediate-scale EGS reservoir creation processes and related model validation at crystalline rock sites. Cooperative research under the EGS Collab SIGMA-V project will provide a foundation of knowledge and modeling capability that form a bridge to meeting the challenges of FORGE.

Expediting R&D through Community Focus: Brady Hot Springs, NV

As an existing geothermal production field with a diverse geology amenable to both hydrothermal resources and EGS, Brady Hot Springs in Nevada has been a target of geothermal development for decades. Over the last six years the site has become a hotbed of activity for innovative geothermal R&D.

Brady Hot Springs is a geothermal field that produces power in a sparsely populated region of northern Nevada. Operated by Ormat Technologies since 1992, this field hosts six production wells and supplies approximately 14 MW of electricity to the grid. The location also supports a robust research community due to the amount of publicly available data, length of operations, relatively shallow (3000-6500 ft.) geothermal reservoir, and relatively high reservoir temperatures (350°-400°F).

With the nearly constant and frequently overlapping research efforts at Brady Hot Springs over the years, a unique community has formed. Scientists, engineers, geothermal operators, and utilities work comfortably together in a collaborative ecosystem in which everyone works toward similar goals and leverages mutual work and data, toward the complementary goals of understanding the geothermal reservoir, improving its economics, and broadening our scientific understanding of the subsurface. The project team is large and pulls in a wide variety of specialties and backgrounds, including researchers from Ormat, Temple University, University of Nevada-Reno, Lawrence Livermore National Lab (LLNL), Lawrence Berkeley National Lab (LBNL), and Silixa.

The University of Wisconsin-Madison team, with established and readily available lessons learned and best practices, completed the permitting necessary for field work on an impressive timeline. Due to the number of entities involved, the uniqueness of innovative field research, and the site itself, permitting timelines require tight management and thorough communication. The collaborative ecosystem built slowly over the years through ongoing geothermal research at this site has facilitated communication and management in this case, and field work is underway. This is only the most recent example of relationship-driven efficiency; the site is host to a number of these cases, and it certainly won't be the last.

The team at Brady Hot Springs includes scientists and engineers from: University of Wisconsin-Madison Department of Geoscience; Ormat Technologies, Inc.; Silixa Ltd.; University of Nevada-Reno; Temple University; Lawrence Livermore National Laboratory; and Lawrence Berkeley National Laboratory. | Photo by Dan Koetke

In the spring of 2016, the team collected a wide array of data from Brady Hot Springs, and is currently working on that data's integration into a single, clear picture of the Brady Hot Spring geothermal reservoir. Many terabytes of data are currently available on the Geothermal Data Repository and the project is projected to produce a validated small-scale prototype by the end of FY 2017.

Building Upon Previous EGS Accomplishments: Raft River, ID

A major long-term goal of the GTO is to realize EGS technologies' vast potential through commercial, cost-competitive, EGS power production. In pursuit of this goal, GTO funds support field demonstrations to facilitate new, innovative technology deployment and validation to reduce costs and improve performance of these man-made geothermal reservoirs. To build upon previous EGS demonstrations successes, GTO and the University of Utah continued to push EGS technologies forward with ground breaking accomplishments at the Raft River Geothermal Field in Idaho.

The Energy & Geoscience Institute at the University of Utah demonstrated stimulation techniques that connect a previously isolated injection well to the existing production wells. This effectively makes existing geothermal reservoirs larger, and adds more electricity to the grid.

Specifically, the larger reservoir will yield an astonishing 2.5 MW electric, approximated through innovative reservoir testing, and eliminate the need to drill another $3 million-$4 million injection well closer to the main well field. The team's success at the Raft River EGS project demonstrates the importance of low pressure thermal stimulation as a primary and very effective mechanism for improving well injectivity, in conjunction with strategic high-rate stimulation techniques.

The final phase of this project will consist of long-term data collection and analysis activities to understand the creation and evolution of an EGS reservoir that is connected to an existing geothermal reservoir. The data collected here will further advance EGS technology demonstrations and deployment, further contributing to the advancement of EGS commercialization.

The RRG-9 ST-1 wellhead fitted with a lubricator. A distributed temperature sensor was run through the lubricator to measure well bore temperatures. Photo source: Energy & Geoscience Institute at the University of Utah.

Collaborative Optimization: PNNL Code Comparison

Over the past three years, Pacific Northwest National Laboratory (PNNL) has supported GTO in organizing and executing a first-of-its-kind geothermal code comparison study. This project sought to test, improve, and diagnose differences among a collection of cutting-edge numerical simulators available to support geothermal energy development. The objective of this effort was to gather renowned modeling experts from the national laboratories and universities in order to benchmark current codes, enable improvement and verification, build confidence in the suite of available numerical tools, and ultimately identify critical future development needs for the geothermal modeling community to accelerate the development of understanding the subsurface for optimizing EGS development. Throughout an EGS lifecycle, the reservoir is a dynamic system which requires thorough understanding of tightly coupled thermal, hydrologic, geomechanical, and chemical (THMC) processes, rendering numerical simulation an essential tool in the geothermal community.

Participating teams on the study are principally from the United States and include those from universities, industry and DOE National Laboratories: Lawrence Berkeley National Lab, Pacific Northwest National Lab, Lawrence Livermore National Lab, Idaho National Lab, Los Alamos National Lab, Oakridge National Lab, University of Oklahoma, University of Nevada-Reno, Stanford University, Penn State University, University of Texas at Austin, and Itasca Consulting Group. These teams have unique numerical simulators and analytical approaches, providing a diverse set of mechanistic approaches, modeled processes, and solution schemes.

New Drilling Technology Could Drive Advances in America's Geothermal Energy Industry

Accessing geothermal resources in deep subsurface conditions can prove difficult because of the extreme environments found there. Engineers often encounter extreme temperatures, extreme pressures, and crystalline rock formations. That is where highly advanced drilling technologies and techniques—pushing the envelope of what can be achieved in conventional drilling operations—come in.

To overcome these challenges, Baker Hughes Incorporated, a global oilfield services company, has collaborated with GTO to develop and successfully demonstrate an advanced drilling system designed for these critical conditions. This technology can drill directionally at extremely high temperatures (572°F). The system uses a high-temperature lubricant in the drilling fluid, a full metal drill bit to break the formation, and a full metal drilling motor known in the drilling industry as a "metal-to-metal motor."

In 2016, Baker Hughes successfully directionally drilled with this innovative system in a deep geothermal well. In fact, the metal-to-metal motor operated for a continuous 270 hours – the longest time that a system like it has ever operated.

Because of its reliability in extreme subsurface conditions, the successful deployment of this drilling system could have far-reaching impacts. This technology advances the state of geothermal technologies and opens more geothermal resource areas for development, including the immense EGS resource.

The energy resources that this breakthrough could make available to developers will be immense, and the potential economic impacts are currently undefined. As the geothermal, oil and gas, and nuclear industries adopt this cutting-edge technology throughout the nation's energy portfolio, Baker Hughes and GTO's research in drilling technology could help put our nation on a path toward improved energy security and a stronger economy.

A Baker Hughes geothermal drilling operation in progress.

Geothermal Wells - Advancing the Technology

One of the most critical components of geothermal resource development is the drilling process and the integrity and longevity of a geothermal well's cementation of casings. After a geothermal production well has been drilled, the well must be stabilized with casing, a large diameter pipe that is assembled and inserted into a recently drilled section of the borehole, in order to prevent the walls from collapsing. The gap between the casing and the borehole walls (the annulus) is filled with cement, which locks the casing into place. Within geothermal wells, cement and casing integrity challenges are increased by the harsh conditions of high temperature, high pressure, and caustic environment that can degrade conventional cement.

With assistance from GTO, Trabits Group, LLC successfully developed a cement that outperforms traditional cements in harsh geothermal conditions and is easy to deploy. Containing zeolites, a naturally occurring mineral that can be readily dehydrated and rehydrated, this cement reduces the complexity and cost of well cementing, which will help enable the widespread development of geothermal energy in the United States.

Benefits of the newly developed cement include:

Cost Savings - Reduces the time and complexity of well cementing, lowering the overall cost of well completion.

Ease-of-Use - Provides compatibility with all common additives (e.g., retarders and accelerators) and minimizes the effect of down-hole temperature.

Environment - Reduces greenhouse gas emissions compared with Portland cement production by using naturally occurring zeolites.

Development of this cement marks another successful step toward harnessing and accelerating the deployment of geothermal energy and increased domestic energy security by reducing barriers to geothermal energy access.

High pressure cement testing. Photo Courtesy: Trabits Group

Geothermal Plant, Hudson Ranch, Salton Sea, CA

Reducing Drilling Barriers: Sandia National Lab and Atlas Copco Hammer-Drill

A GTO funded collaboration between SNL and industrial manufacturer Atlas Copco has resulted in a new type of downhole hammer that can endure the heat required for geothermal drill-ing. The downhole hammer is capable of drilling geothermal boreholes in temperatures as high as 572°F.

A critical piece of the project was developing lubricious coatings, which help reduce friction between parts, important in geothermal operations. Oil and elastomer/plastic parts in traditional downhole hammers are unable to withstand the high temperatures in geothermal environments. Additionally, SNL researchers constructed a high-operating temperature (HOT) drilling facility to test the performance of the hammer under extreme conditions. Utilizing the facility, researchers could simulate conditions deep underground, including drilling into different types of rock like the granite commonly found in geothermal-rich areas.

A key step in the expansion of geothermal energy is the lowering of exploration drilling and development costs, which the new downhole hammer helps tackle. Continued technologies that reduce upfront cost barriers in geothermal development will help enable the expansion of geothermal energy, contributing to our domestic energy security.

Industry partners recognize the potential of this technology and have indicated interest in demonstrating the tool in a real geothermal environment in 2017. By maximizing the rate of penetration through hammer drilling, this deployment would demonstrate a reduction of drilling costs and lower a significant barrier to geothermal development.

GeoVision Study – Assessing Geothermal Capabilities

The Geothermal Vision Study (GeoVision) is a multi-year, multi-stakeholder research initiative undertaken by GTO and is similar in scope and approach to DOE's prior vision studies focused on wind, solar, and hydropower technologies. The analysis is conducted to a significant extent by DOE's system of national laboratories to encompass the latest in geothermal technology advances. The goal of the GeoVision is to conduct credible analysis of potential geothermal growth scenarios through 2050 across multiple market sectors relative to a business-as-usual case. The GeoVision Study will help GTO develop a research, development, demonstration, and deployment (RDD&D) roadmap to chart a course for meeting the necessary cost and performance targets used in the modeled improvement scenarios.

The GeoVision is an energy-sector-wide assessment of the advantages to and impacts on economic, environmental, and social metrics related to the penetration of geothermal technologies into the U.S. market. In this instance, market sectors will include existing and potential electric generation, direct thermal applications, and other additive value streams, which augment the cost and/or performance of developing a geothermal resource. The study relies on the collection, modeling, and analysis of robust datasets through national laboratory partners, and it is peer reviewed by a diverse group of industry peers ("Visionaries"). The key question addressed by the GeoVision study is "How can geothermal energy to become a material contributor to the U.S. energy supply by the year 2050?" Thus, the results of the study will identify the potential for geothermal energy to be an essential part of the national energy mix. By engaging the geothermal industry in this dialogue, GTO anticipates a product that benefits the entire industry.

GEOVISION

Creating Tools for Better Analyses

In 2016, GTO released an updated version the Geothermal Electricity Technology Evaluation Model (GETEM). After the update announcement, the GETEM user base increased with an additional 250 downloads, making 2016 the highest GETEM activity year to date. GETEM is a detailed model of the estimated performance and costs of currently available U.S. geothermal power systems. GETEM can be used to analyze and evaluate currently available technologies and to estimate the cost of certain technologies 5 to 20 years in the future, given the direction of potential RD&D projects. The model is intended to help GTO determine which proposed RD&D programs and projects might offer the most improvements for the taxpayer dollar.

Engaging US Small Businesses: SBIR/STTR and SBV Pilot

GTO has continued to engage the US small business community through the Small Business Innovative Research and Small Business Technology Transfer (SBIR/STTR) program and the Small Business Vouchers (SBV) pilot program. These programs help American small and medium size businesses develop their great ideas with an eye toward commercialization in order to allow for the wider deployment of geothermal energy.

In 2016, GTO funded 11 SBIR/STTR awards across a broad array of geothermal technologies. Some of these were in collaboration with the Office of Science in support of the SubTER crosscut. This includes a project with GroundMetrics, Inc., who is developing a technique that uses the well-casing as an electrode and surface based sensing of the electrical fields as a non-invasive and economical option to map wellbore integrity. Another award was made to Aerodyne Research, Inc., who completed a Phase I study on using geothermal heat for the hydrothermal liquefaction of algae in a cascading system that could create an additional revenue stream for geothermal operators. Subject to appropriations, additional GTO SBIR Phase I awards are expected to be made throughout 2017.

GTO also participated in the SBV Pilot program, a new initiative with the goal to help entrepreneurs engage with the vast wealth of knowledge and resources at the Department of Energy's National Laboratories. In 2016 GTO awarded six vouchers through the SBV Pilot to fund the National Labs to provide small businesses with technical assistance and cooperative research and development. For example, one of the vouchers was awarded to Elko Heat Company to explore the development of geothermal resources in the City of Wells, Nevada. This project will see scientists from Lawrence Berkeley National Laboratory, National Energy Technology Laboratory, and United States Geological Survey join their small business and local government partners to gather and analyze geologic data, develop a resource model, and assess the economic viability of a geothermal district heating system. By switching to geothermal, the City of Wells hopes to reduce heating costs and attract new businesses to its revitalized downtown.

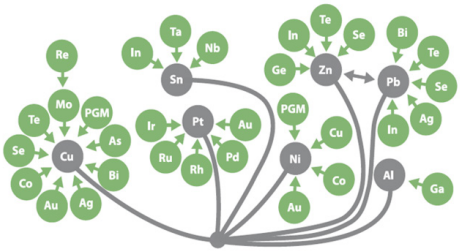
In just a 12-month period, GTO supported 21 small businesses in 15 different states across the nation through the SBIR/STTR and SBV Pilot programs. These companies hail from the current geothermal powerhouses (California, Nevada, and Utah) and states with emerging resources (Texas, Colorado, New Mexico, and Washington) to states with less geothermal development (Arkansas, Massachusetts, New Hampshire, North Carolina, Ohio, Oklahoma, Pennsylvania, and Virginia). GTO continues to support small businesses' geothermal innovations and looks forward to continued engagement with our nation's engines of economic growth.

SBIR · STTR
America's Seed Fund

Small Business Vouchers Pilot
U.S. DEPARTMENT OF ENERGY

Extracting Critical Materials from Geothermal Brines

As part of GTO's Mineral Recovery efforts in 2016, up to $3.8 million was awarded to four R&D projects to assess the occurrence of rare-earth minerals and other high-value, critical or strategic materials that may be dissolved in higher-temperature fluids associated with geothermal energy extraction. Critical materials like rare-earth elements and lithium play a vital role in many clean energy technologies, including solar panels, wind turbines, electric vehicles, and energy-efficient lighting. More of these materials—which are of high value or critical to U.S. businesses and other national interests—may become available and economically recoverable through this and recently completed research.



Many critical metals are byproducts of base elements with essential, wide-ranging uses across multiple domestic industries.

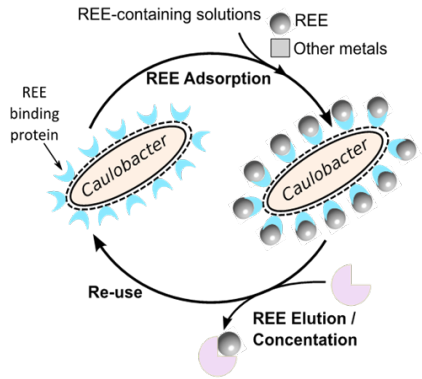
The selected R&D projects are:

- Lawrence Livermore National Laboratory (LLNL), Livermore, California—LLNL will use bioengineered microbes in the design and operation of a rare-earth enrichment and separation process to efficiently deliver high-purity products from geothermal fluids.
- Pacific Northwest National Laboratory (PNNL), Richland, Washington—PNNL will demonstrate a magnetic nanofluid approach to recover rare-earth minerals and other high-value materials from geothermal fluids.
- University of Utah, Salt Lake City, Utah—University of Utah will perform a resource assessment of the western United States to identify high-value materials in geothermal fluids and other fluids produced from energy projects.
- University of Wyoming, Laramie, Wyoming—University of Wyoming will assess rare-earth element concentrations in waters produced by geothermal and oil and gas projects.

By validating methods for recovering and purifying trace materials, the economic and production benefits of geothermal energy projects can be improved, making them more cost-competitive at a wider range of locations. These valuable minerals could also be found in elevated temperature fluids produced by oil, gas, or mining operations. The selected projects will research breakthrough approaches for extracting these materials and quantifying this resource potential, which represents an opportunity to help meet America's need for domestic materials while strengthening the economic viability of geothermal energy operations.

Examining how to economically recover these dissolved materials represents one of a range of R&D efforts GTO is pursuing to secure and diversify the supply of critical materials, identify substitute materials, and develop better ways to recycle these materials. Results from this work will enhance current applications of geothermal energy, support planned development, and potentially open additional U.S. regions for future projects.

National Labs: Micro Miners and Mineral Recovery



Lab Corps Micro Miners

DOE's complex of National Laboratories is a treasure trove of scientific expertise and innovations. In an effort to help deploy these innovations, EERE has developed an entrepreneurship "boot-camp" for National Lab researchers called Lab-Corps. Modeled after the National Science Foundation's Innovation Corps (I-Corps™), Lab-Corps is a six-week intensive training course where selected researchers conduct more than 100 customer interviews and use the business model canvas to explore potential commercialization pathways for their technologies.

Since the fall of 2015, EERE has run four Lab-Corps cohorts, developing the entrepreneurial skills of more than 50 teams of lab researchers by having them exploring the business cases for their cutting-edge energy technologies. GTO has sponsored five teams to participate in Lab-Corps, exploring technologies ranging from compressed air energy storage and geophysical modeling software to geothermal desalination and high temperature electronics packaging.

In 2106, GTO sponsored a group of researchers from LLNL investigating mineral recovery from geothermal brines. The LLNL team, which called themselves Micro Miners, is researching a cost-effective and eco-friendly biotechnology that can recover rare earth elements from low-grade sources such as geothermal fluids. As part of Lab-Corps, the Micro Miners team explored many business cases for this technology which has the possibility to help make geothermal development more economical while further diversifying the global rare earth supply chain.

For more information visit the DOE Lab-Corps website: https://energy.gov/eere/technology-to-market/lab-corps

Combining Three Clean Energy Sources in One: Stillwater, NV

Engineers added a 2MW solar thermal power plant to support the existing geothermal plant. The thermal energy increases the temperature of the geothermal fluid entering the plant, increasing overall output.

GTO provided funding to Enel Green Power's Stillwater Power Plant to explore the integration of geothermal and solar thermal heat sources for the generation of electrical power. Funding was also provided to National Renewable Energy Laboratory (NREL) and Idaho National Laboratory (INL) for advisement to Enel. As the first-of-its-kind hybrid plant, the technology has the potential to allow for increased power generation during the middle of the day when electrical demand is generally greatest, to use solar heat to offset long-term decreases in geothermal resource performance, and to leverage geothermal heat to eliminate the necessity for thermal storage, which is required by stand-alone concentrated solar power plants.

As a result of this investment, the Stillwater Power Plant was commissioned in Nevada in March 2016, marking the establishment of the world's first triple hybrid facility combining geothermal, photovoltaic, and solar thermal power generation. The event was attended by Italy's Prime Minister, Nevada's Governor, and DOE staff, and represented the culmination of a tremendous collaborative effort by DOE and its partners. The newly commissioned plant has the capacity to produce enough renewable energy to meet the needs of 15,000 American households.

Desalination: Reducing a Waste Stream

Many oil and gas wells produce heated fluids, a geothermal resource that is almost always overlooked and wasted. These fluids are viewed as a burden to the operators as they have too high a concentration of dissolved solids for use, and current technologies to treat the waters are not economical.

This situation presents an opportunity to put the wasted co-produced geothermal resource to use in the treatment of produced waters. GTO is investigating desalination technologies that use thermal energy to treat highly saline waters rather than the standard pressure-difference treatment techniques.

In 2016 GTO continued to fund R&D of two desalination technologies: INL is leading a team developing switchable polarity solvent forward osmosis and NREL is leading a team working on membrane distillation. Both of these technologies use a thermal gradient as the primary driver to treat the highly saline waters. As these technologies make use of the wasted geothermal heat resource, they offer the potential to reduce the cost of operations in oil and gas production while offering access to new water resources. The thermal desalination processes developed by GTO can help the United States improve both energy and water security.

Collaborating on Solutions to Subsurface Energy Challenges

Subsurface Technical and Engineering RD&D (SubTER)

Energy sources originating from the Earth's subsurface constitute the Nation's primary source of energy, providing more than 80 percent of total U.S. energy needs. Discovering and effectively developing these resources, while mitigating impacts of their use, is critical to the nation's secure, affordable, and sustainable energy future.

Depressed oil and gas prices have recently led to a severe tightening of private industry R&D budgets, with a loss of at least $500M between 2013 and 2015. This has negatively impacted the pace of innovation, and the U.S. risks loss of its leadership position in the energy geosciences. SubTER is DOE's response to these challenges and opportunities. The SubTER Crosscut team— including representatives from DOE's GTO, Fossil Energy, Nuclear Energy, Office of Science, and Environmental Management — fosters strategic partnerships with private industry, DOE national laboratories, and academia.

Next-generation advances in subsurface technologies will: enable prudent development of domestic oil and natural gas supplies; accelerate the deployment of sustainable fossil fuels by providing safe storage capacity for carbon dioxide; enable the deployment of up to 100 GWe of geothermal energy; and provide alternative disposal solutions for DOE-managed radioactive waste.

Success in each of these areas requires mastery of the subsurface, including the ability to adaptively control subsurface fractures and fluid flow. Meeting current and future energy challenges requires dramatic advances in technology to ensure safe, sustainable, and affordable availability of natural resources and storage in the subsurface. SubTER will accelerate real time tracking of subsurface resources and conditions, improve access to these resources, and achieve adaptive control of the subsurface by focusing emphasis on four core pillars: Wellbore Integrity & Drilling Technologies, Subsurface Stress & Induced, Permeability Manipulation & Fluid Control, and New Subsurface Signals.

For more information visit energy.gov/subserface-tech-team-subter.

SubTER Industry Roundtable

Recognizing that the subsurface industry has performed a tremendous amount of research on aspects related to the SubTER pillars but that many industry R&D advances are proprietary, the SubTER Tech Team sought honest feedback about the potential value of the proposed SubTER research plan from industry leaders. To meet this objective, in February 2016, the SubTER team hosted an Industry Roundtable at the Rice University's Baker Institute for Public Policy in Houston, Texas. The Roundtable included 23 industry participants, state and national regulators, and academics who are associated with many subsurface energy sectors, including: oil and gas, geothermal, CO_2 sequestration, and nuclear waste disposal.

The outcome of the roundtable indicated that even large companies dedicate only a very small fraction of R&D funding to long term challenges, such as adaptive control of fractures and flow. The majority of research within industry is driven by business units and markets. Attendees stressed that the challenging nature of solving these national scale issues will likely require long-term Federally-funded research. Several attendees highlighted the current opportunity for the Federal government to change the paradigm of subsurface characterization, permeability control and risk management, given the current downturn in the subsurface energy sector and accompanying low level of research and activity.

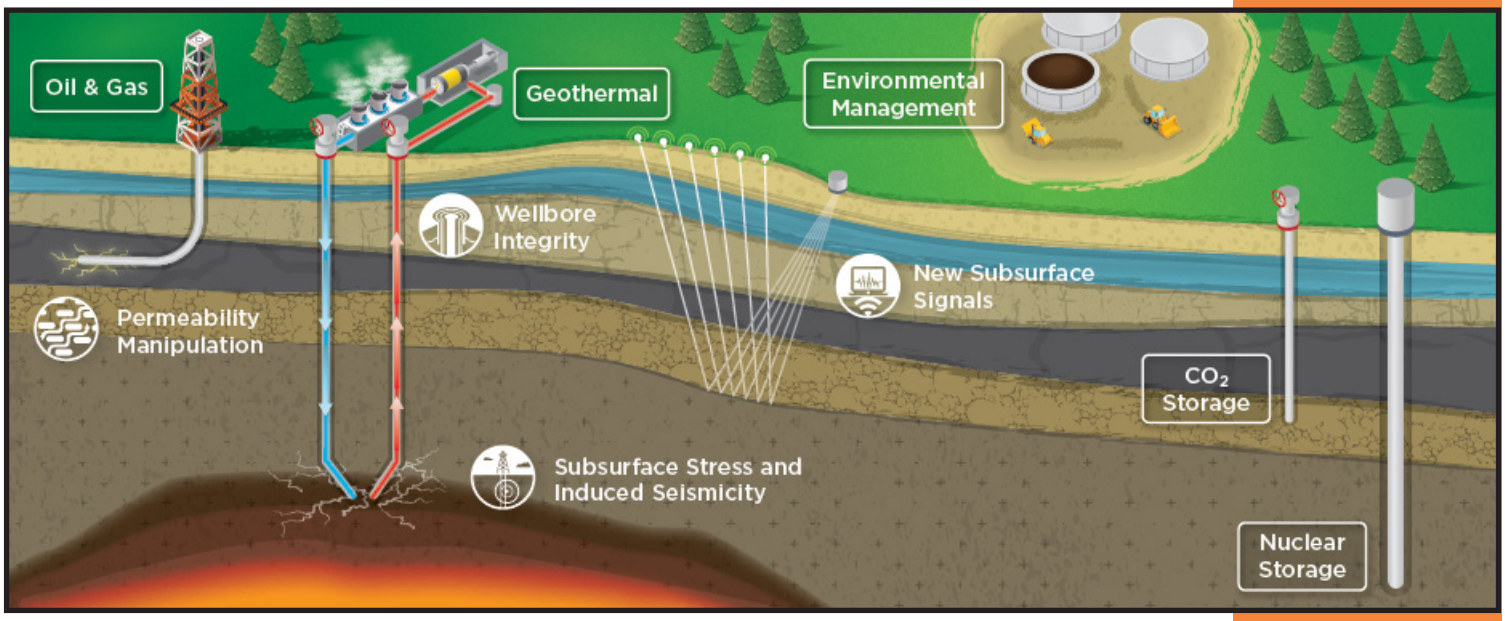
Collaborating on Solutions to Subsurface Energy Challenges

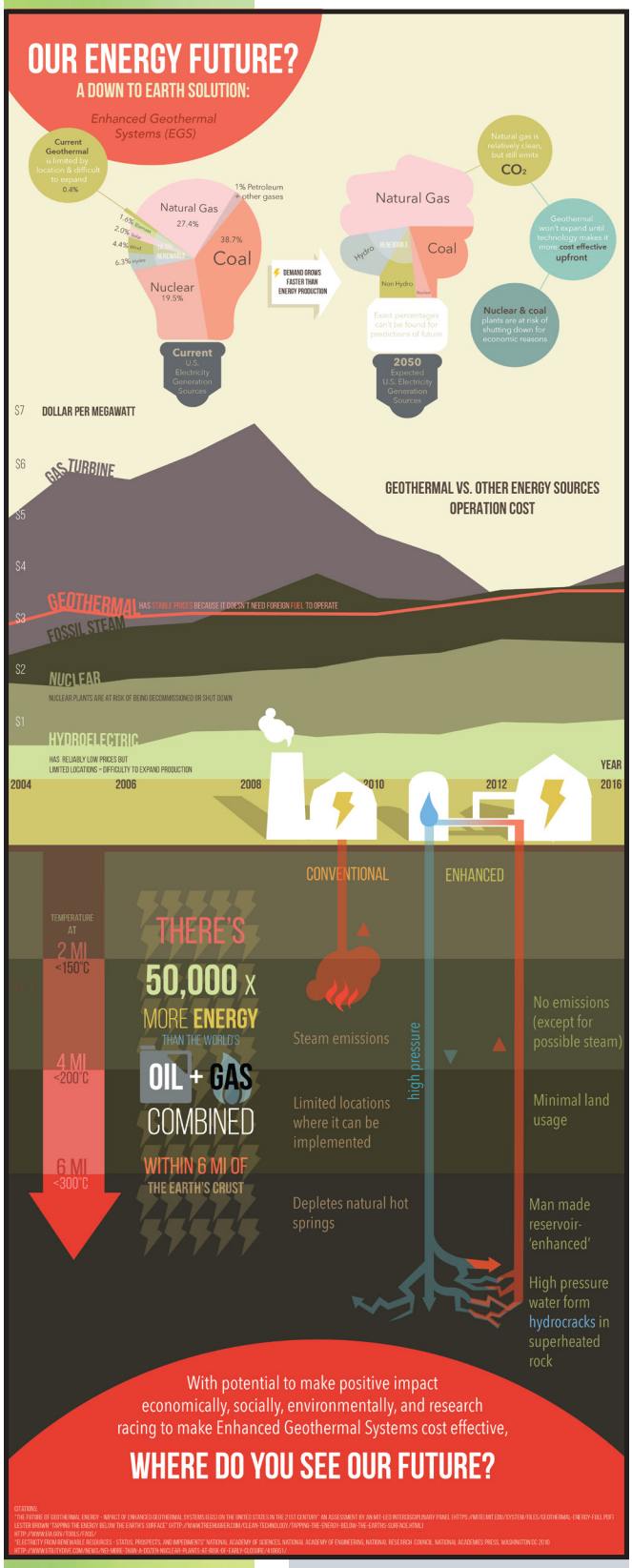
SubTER Awardees to Advance Geothermal Exploration and Carbon Storage

In 2016 GTO and the Office of Fossil Energy (FE) announced the selection of eight new R&D projects to receive a total of $11.5 million in federal funding under DOE's SubTER Crosscut initiative. The new projects are focused on furthering geothermal energy and carbon storage technologies, and will be funded by GTO and FE's Carbon Storage program. The project selections fell under two objectives: (1) deploy and validate prototype carbon storage monitoring, verification, and accounting (MVA) technologies in an operational field environment, and (2) identify and validate new subsurface signals to characterize and image the subsurface, advancing the state of knowledge in geothermal exploration.

SubTER Conducts National and International Outreach

The SubTER Tech Team conducted public outreach at several of the largest geosciences annual meetings including: Geological Society of America (GSA), Geothermal Resources Council (GRC), and American Geophysical Union (AGU). At these meetings, SubTER representatives from DOE and the national labs engaged in informational side-sessions, maintained a SubTER exhibition booth, and presented results of active projects. The SubTER Tech Team also worked closely with the international community by engaging with colleges at the Alberta Geological Society and NRCAN, a Canadian based energy management company. Working with these international groups allows for further collaboration and advancing strategic partnerships. Collaboration efforts will also continue with the Advanced Energy Consortium (AEC) led by the Texas Bureau of Economic Geology, supported by three DOE offices (EERE, FE, and EM). The collaboration with AEC is imperative to the crosscut by allowing academic researchers and industry partners to provide insight on R&D results on subsurface challenges to the DOE and national labs.





The grand prize winning graphic "Infinity and Below", Carnegie Mellon University

GTO Crowns the Victors: Student Competition – Design Challenge 2016

In partnership with the Center for Advanced Energy Studies and Idaho National Laboratory, GTO selected the winner of the Geothermal Design Challenge from more than 100 teams of high school and university (undergraduate and graduate) students invited to explore the future of geothermal energy and literally "draw the heat beneath your feet." Teams of two to three members each collected and interpreted geothermal data in order to design an infographic that tells a compelling story about the future of geothermal energy. For the Challenge, GTO and its partners selected the theme, "What is the Future of Geothermal Energy? How Will It Impact You?"

The competition consisted of three rounds including graphic design, a geothermal energy mentor collaboration, and a social media campaign utilizing everything from Facebook to YouTube to try to capture the public's attention. Following the end of the competition, one high school team, one college team, and one grand prize winner was selected.

The grand prize was award to the team comprised of Tiffany Lai, Susie Lee, and Marisa Lu from Carnegie Mellon University entitled "Infinity and Below." Upon entering the competition, these design majors were aware of renewable energy sources like wind and solar but geothermal energy was a new concept for them. As design students with a broad base of design experience under their belts but little technical background in the physical sciences, the team found the research and translation of unfamiliar, complex technical concepts into visual elements the most rewarding component of the Challenge. As a result of the competition, they not only have an increased awareness about geothermal systems and the role this renewable energy source plays in the future of energy choices, but they have also honed their skills as science communicators and researchers. They are welcome additions to the broadening geothermal stakeholder community and have emerged as highly-sought-after interdisciplinary design students!

Overall, communication, planning, and understanding how to work within a team was a significant lesson learned that will surely benefit them as they develop professionally.

To view the winners please visit: caesenergy.org/geothermaldesign/geothermal-design-challenge-2016-winners/

GTO Honored for Contributions to the Geothermal Industry

GTO and the University of North Dakota (UND) received the GEA Honors award for Technological Advancement. This award recognizes the development of a new, innovative, or pioneering technology to further geothermal development. The DOE and UND partnership earned this award for launching the first commercial project that produces geothermal power from an oil and gas well.

The project was recognized for significant contributions to the development of the geothermal industry. The GEA, along with its member companies, formed the GEA Honors award program to showcase the most inspiring developments in the geothermal industry. Criteria for award selection include:

- involvement in the industry;
- leadership and success;
- positive overall environmental footprint; and
- the creation of jobs.

GTO and UND were presented with the award at the Baseload Renewable Energy Summit in Reno, Nevada in June 2016. By optimizing the value stream for electricity production and related uses, GTO aims to make geothermal energy a fully cost-competitive, widely available, and geographically diverse component of the national energy mix.

Resources

GTO makes the following tools and resources available for free and public use. Click or visit the links below to learn more about these resources.

Reports

- **EGS Roadmap**—A technology roadmap for strategic development of enhanced geothermal: systemseere.energy.gov/geothermal/pdfs/stanford_egs_technical_roadmap2013.pdf
- **Exploration Roadmap**—A roadmap for strategic development of geothermal exploration technologies: geothermal.energy.gov/pdfs/exploration_technical_roadmap2013.pdf
- **Low-Temperature, Coproduced, and Geopressured Geothermal Technologies Peer Review Presentations**—Complete collection of technical presentations from GTO's 2015 Peer Review: energy.gov/eere/geothermal/2015-peer-review-presentations-geothermal-energy
- **GTO 2015 Peer Review Technical Report**—Comprehensive final report summarizing GTO's 2015 Peer Review: energy.gov/eere/geothermal/downloads/2015-peer-review-report-geothermal-technologies-office
- **Latest GTO presentations:** energy.gov/eere/geothermal/presentations
- **JASON Study on EGS**—A report conducted by the JASON group on EGS: eere.energy.gov/geothermal/pdfs/jason.final.pdf
- **JASON Study on Subsurface Technologies**—Findings from a study on subsurface technologies: energy.gov/articles/2014-jason-report-state-stress-engineered-subsurface-systems
- **Quadrennial Technology Review (QTR)**—energy.gov/quadrennial-technology-review-2015

Tools

- **Geothermal Prospector**—A mapping tool developed for the Geothermal Power industry. This tool is designed to help developers site large-scale geothermal plants by providing easy access to geothermal resource datasets and other data relevant to utility-scale geothermal power projects: nrel.gov/gt_prospector
- **Geothermal Regulatory Roadmap**—A centralized information resource on the permitting processes for geothermal development in Alaska, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, and Texas: en.openei.org/wiki/RAPID/Roadmap/Geo
- **The Geothermal Electricity Technology Evaluation Model (GETEM)**—A detailed model of the estimated performance and costs of currently available U.S. geothermal power systems: eere.energy.gov/geothermal/getem/DownloadTools.aspx
- **The Jobs and Economic Development Impact (JEDI) Geothermal Model**—Allows users to estimate project costs and direct economic impacts for both hydrothermal and EGS power generation projects based on exploration and drilling activities, power plant construction, and ongoing operations: nrel.gov/analysis/jedi/about_jedi_geothermal.html
- **National Geothermal Data System**—geothermaldata.org

Find answers to the most frequently asked questions and more resources at http://energy.gov/eere/geothermal/geothermal-basics

Acronyms

AGU	American Geophysical Union (industry association)
CO_2	Carbon Dioxide
DDU	Deep Direct-Use
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EGS	Enhanced Geothermal System
EM	Office of Environmental Management
FE	Office of Fossil Energy
FORGE	Frontier Observatory for Research in Geothermal Energy
FY	Fiscal Year (October 1 through September 30)
GEA	Geothermal Energy Association (industry association)
GETEM	Geothermal Electricity Technology Evaluation Model
GPM	Gallons Per Minute
GRC	Geothermal Resources Council (industry association)
GSA	Geological Society of America (industry association)
GTO	Geothermal Technologies Office
GW	Gigawatt
GWe	Gigawatt (electric)
INL	Idaho National Laboratory
kWh	Kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
LCOE	Levelized Cost of Electricity
MW	Megawatt
MWe	Megawatt (electric)
NETL	National Energy Technology Laboratory
NREL	National Renewable Energy Laboratory
PFA	Play Fairway Analysis
PNNL	Pacific Northwest National Laboratory
R&D	Research and Development
RD&D	Research, Development, and Demonstration
SBIR/STTR	Small Business Innovative Research and Small Business Technology Transfer
SBV	Small Business Vouchers
SNL	Sandia National Laboratory
SubTER	Subsurface Technology and Engineering Research, Development, and Demonstration (crosscutting initiative at DOE)
UND	University of North Dakota (Academia)

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2016 Annual Report Geothermal Technologies Office

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